Agent Based Evidence Marshaling: Discovery-Based Enhancement Tools for C2 Systems

Carl W. Hunt
Lieutenant Colonel, US Army
US Army Criminal Investigation Command
8652 Morning Star Ct.
Springfield, VA 22153
USA
[1] 703-805-3528
huntc@belvoir.army.mil

ABSTRACT

Developers introduce new technologies at rates that defy prediction. This phenomenon applies to both new and existing sources of information, as well. As the recent attacks on America demonstrate, the result is an ever-increasing glut of information competing for our attention in ways that are unprecedented in history, potentially bringing even the most sophisticated command and control (C2) tools and practices to their knees. Conventional methods for organizing and focusing information for C2 purposes do support the current situation; for example, the scenario is one of the major methods in view within the NATO Guide to Best Practice in C2 Assessment for this purpose. Scenarios can be of immense value in evaluating information and relationships of that information to various C2-related environmental constraints. The methods by which we construct and interact with scenarios must be subject to constant review, however. This paper offers novel methods for scenario development and interaction, based on modeling techniques that embrace multidisciplinary thinking – the agent-based model. In fact, a meaningful method for better understanding how life and the massive information it routinely processes may actually be manifested in straight-forward uses of agent-based models. This paper describes an agent-based model called the Agent Based Evidence Marshaling (ABEM) model, and discusses ways to enhance scenarios that support Best Practices in Command and Control. ABEM brings to convergence centuries-old studies of semiotics and inference with recently introduced models for discovery and insight within an agent-based modeling environment – scenario development is one of ABEM's primary objectives.

Key Words*: Modeling and Simulation, Scenario Generation and Testing, Decision Support.*

1.0 INTRODUCTION

Developers introduce new technologies at rates that defy prediction. This phenomenon applies to both new and existing sources of information, as well. As the recent attacks on America demonstrate, the result is an ever-increasing glut of information and technologies competing for our attention in ways that are unprecedented in history, potentially bringing even the most sophisticated command and control (C2) tools and practices to their knees. Conventional methods for marshaling and visualizing information for C2 purposes are of modest help to the current situation; for example, the scenario is one of the major methods

Paper presented at the RTO SAS Symposium on "Analysis of the Military Effectiveness of Future C2 Concepts and Systems", held at NC3A, The Hague, The Netherlands, 23-25 April 2002, and published in RTO-MP-117.

Report Documentation Page

Form Approved
OMB No. 0704-0188

1. REPORT DATE **00 DEC 2003**	2. REPORT TYPE **N/A**	3. DATES COVERED **-**

4. TITLE AND SUBTITLE **Agent Based Evidence Marshaling: Discovery-Based Enhancement Tools for C2 Systems**	5a. CONTRACT NUMBER 5b. GRANT NUMBER 5c. PROGRAM ELEMENT NUMBER
6. AUTHOR(S)	5d. PROJECT NUMBER 5e. TASK NUMBER 5f. WORK UNIT NUMBER
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) **US Army Criminal Investigation Command 8652 Morning Star Ct. Springfield, VA 22153 USA**	8. PERFORMING ORGANIZATION REPORT NUMBER
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)	10. SPONSOR/MONITOR'S ACRONYM(S) 11. SPONSOR/MONITOR'S REPORT NUMBER(S)

12. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release, distribution unlimited

13. SUPPLEMENTARY NOTES
See also ADM001657., The original document contains color images.

14. ABSTRACT

15. SUBJECT TERMS

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT **unclassified**	b. ABSTRACT **unclassified**	c. THIS PAGE **unclassified**	**UU**	**22**	

Standard Form 298 (Rev. 8-98)
Prescribed by ANSI Std Z39-18

in view within the *NATO Code of Best Practice in C2 Assessment* (COBP) for this purpose. Scenarios can be of immense value in evaluating information and relationships of that information to various C2-related environmental constraints. The methods by which we construct and interact with scenarios must be subject to constant review, however. This paper offers novel methods for scenario development and interaction, based on modeling techniques that embrace multidisciplinary thinking – the agent-based model. Although labelled *agent-oriented modeling* in the COPB chapter on Methods and Tools, the descriptions of both are sufficiently similar to use the terms interchangeably. For this paper, I employ the term agent-based modeling.

What decision-makers faced with rapid information flux now need is a data-to-decision, scenario-enhanced continuum that offers insights at any point in the cycle in order to increase decision support. Interestingly, increasing sophistication in decision support systems may not even be needed, as life itself substantiates. A meaningful method for better understanding how life and the massive information it routinely processes may actually be manifested in straight-forward uses of agent-based models. Such models can provide data-to-decision enhancement through discovery. This paper describes an agent-based model called Agent Based Evidence Marshaling (ABEM) that has shown promise in enhancing the process of discovery through scenario generation and interaction.

ABEM brings to convergence centuries-old studies of semiotics and inference with recently introduced models for discovery and insight within an agent-based modeling environment – scenario development has always been one of ABEM's primary objectives. The ABEM environment focuses investigators, analysts and decision-makers toward better inquiry about the contents of their knowledge bases. As an enhancement to C2, ABEM provides a discovery-based setting for information to self-organize into meaningful representations of knowledge that potentially expose gaps, sometimes referred to as "what we don't know," or "unknown unknowns" as the NATO COBP labels it. From these visual depictions may emerge new line of inquiry and testable hypotheses, embedded in scenario form, that assist in the search process for evidence or information to fill in the gaps and produce more sophisticated scenarios about the evidence under examination.

This paper is presented into three parts. The first part presents an overview of discovery, semiotics and agent-based modeling, including its root dynamics as a component of Complexity Theory. The second part of this paper introduces the Agent Based Evidence Marshaling model and its potential impact as a C2 discovery-enhancing tool for improving scenario development and interaction. Finally, this paper describes likely extensions of the model into more generalized categories of command and control, interweaving semiotics and complexity theory. Principal findings focus on the enrichment of the processes of nature and agent-based modeling, as enhanced by the process of discovery, to novel methods for C2 planning to increase situational awareness and force protection.

2.0 SEMIOTICS, DISCOVERY AND AGENT-BASED MODELING: ENABLERS FOR EFFECTIVE C2

2.1 Revolutionary or Evolutionary?

Imagine what historians of 100 years from now may think about what many, including the 2002 NATO Code for Best Practice for Command and Control Assessment, claim is a "Revolution in Military Affairs." These historians will weigh the modifications we made in fighting our nations' wars in terms of all contemporary technological advances. As an example, some military historians of today consider that another "revolution" we call information age warfare emerged with the introduction of the technology of the telegraph. In the next 100 years, information-based technologies will populate our world in ways in which we may not even be aware, and will increasingly lead to an understanding of just how close humanity and society (and warfare) parallel the development of life over the past few billion years. Biological information has been at the root of this unpredictable growth, which has actually been much more evolutionary than revolutionary. Our current perspective may suggest revolution, but in the long view, we are living in evolutionary times. Future historians may chuckle that we considered ourselves revolutionaries in warfare. Humility and inspiration from nature are key watchwords for us here.

Whether we label it revolution or evolution, the matter is still of great importance. Let us consider best practices in command and control as products of evolution for the purposes of this paper, however, in order to better understand the model that life provides to the novel information technologies that will lead us toward "best practices." Geopolitics aside, the challenges to understanding how to best leverage new information-based technologies and develop a conceptual dimension for deploying them will be discovered in models of life, eventually following the principles of emergence and self-organization. We may soon lose the ability to optimally engineer simple solutions for complex problems, and rather seek to grow them, in self-organizing fashion, as products of evolutionary improvement. These solutions could significantly enhance best practices for command and control. For eons, life has proven it works well enough through evolutionary processes.

The role of information management and technology, particularly as it has been assisted by artificial intelligence, ranks as one of the prime applications of technological development today. The ability to perform automated complex calculations and to store results for later use has been an objective since even before Charles Babbage's analytical engine of the early 1800's. Information technology and management are of critical importance to almost every facet of modern life. It has only been since World War II and the requirements of major military projects such as the Manhattan Project that we've seen significant breakthroughs in information technology, however. The study of computer science as a major discipline has empowered this growth. At the beginning of the 21st Century, with increased focus on the disciplines of biology, artificial intelligence and complex adaptive systems, we see what may be the beginnings of yet another period of breakthrough in information technology. In the extended view of history, however, these achievements still remain more evolution than revolution.

2.1.1 Complexity Theory and Semiotics

Information technology has also been an empowering mechanism for Complexity Theory and its older cousin, semiotics. Complexity Theory is only now finding its own definitions. In his popularization of the budding discipline ten years ago, Waldrop related that complexity science is "so new and so wide-ranging that nobody knows quite how to define it, or even where its boundaries lie" [Waldrop, 1992]. There are however signature disciplines that compose the sciences and theory of complexity that prepare us for how to think about the relationships of living entities and information management, through the interdisciplinary threads that compose this theory. I suspect that most complexity theorists would agree that complexity deals with the study of complex adaptive systems that embody the interactions of independent agents, in self-organizing schema, that produce emergent phenomena that typically cannot be predicted from observations of the lower level entities that compose the interactions. If we find clues from nature, the ideas resulting in the development of the concepts of semiotics, we have powerful heuristics to shape our understanding.

The major disciplines that compose complexity theory include biology, physics, economics, psychology, mathematics and the computer sciences. There are also other disciplines that have been applied to the study of complex adaptive systems. The real focus is on the idea that complexity embraces a variety of studies that have at their root the quest to understand how organic (and even inorganic) entities come to exist and behave in the manner in which they do. In that way, Complexity Theory displays keen similarities to semiotics, the study of signs and systems that rely on signs, such as nature herself. The better known study of semantics is in fact an examination of linguistic signs such as words, searching for connections to ideas and thoughts through meaning. Semiotics also looks for meaning in the broader context of nature.

The study of complexity is the study of life's entities and the environment in which life exists, and how these entities interact with each other to produce the behaviors that we can ultimately observe. Complexity studies have borrowed important concepts from each other, often in metaphorical terms, in order to explain how things interact, work and prosper, including information. In fact, Charles S. Peirce and Richard Dawkins argued that ideas can be alive and propagated through human life. Dawkins called these living ideas *memes* [Dawkins, 1989], while Peirce characterized them as "substantial things" [Buchler, 1955, 340]. This concept and the study of memetics that accompanies it also manifest in the thinking behind complex adaptive behavior [Blackmore, 1999].

2.1.2 Peirce, Abduction and Complexity Theory

Peirce's thoughts about the inference model he called abduction and the notion of living ideas are fundamental to the concept of emergence, as discussed throughout this paper. In fact, Peirce's descriptions suggest that he considered ideas to have a living force or "energy" and that ideas may even be capable of interacting with other ideas and produce their own force. He spoke of how "all mind is directly or indirectly connected to all matter" [Buchler, 353], and how there is such a thing as "a living idea" [349]. In coming very close to describing emergence, Peirce writes, "A finite interval of time generally contains an innumerable series of feelings; and when these feelings become welded together in association, the result is a general idea" [346]. Here Peirce describes living feelings, interacting with other living feelings, to produce what can only be characterized as living ideas. It is this essentially undirected emergence that can improve the way we "live" and interact with our information in the world of command and control. Now, when we tie the ideas of emergence to the concept of discovery, we begin to see the power that nature may truly wield in information technology. We must consider these notions in the light of "best practices" in command and control.

If ideas are alive, intellectual creativity and discovery through abduction is a life-producing process. Can we borrow from nature meaningful ways to enhance information technology in a method that stimulates discovery and our production of creative ideas – ideas that we can visualize in the building of novel agent-based scenarios? Can we "artificially" stimulate the creation of ideas in silicon that boost our human creativity, even borrowing from the apparent successful model of "living" memes so that we might discover what we didn't know or was obscured by masses of data before? If this is indeed possible, then biology and the other complexity sciences provide models for how we may emulate natural creativity. These models are manifested in agent-based modeling, a significant mechanism for discovery that has grown out from the disciplines embodied in complexity theory [Axelrod, 1997, 3-4]. Agent-based models can provide powerful reflections of life-like properties.

Harvard biologist Edward O. Wilson notes that multi-disciplined approaches to understanding our world are hardly new. Wilson writes of an "Ionian Enchantment," a belief in the unity of sciences in the times of Thales of Miletus of sixth century B.C. Greece, and an inspiration to Aristotle. Wilson recounts how the Age of the Enlightenment, a time of exploring the intersections of scientific disciplines, was corrupted by the politics and religiosity that preceded the French Revolution [Wilson, 1998, 4-15]. Basically, until the separation of the sciences into various disciplines, a likely by-product of the industrial revolution, all the sciences lumped together were known as "natural philosophy." Even Francis Bacon, representative of history's greatest natural philosophers, speaks of manifest properties arising out of inner structures in his discussions of "latent schematisms" of matter [Bacon, pub. 1994]. Complexity theorists talk of these "manifest properties" as the results of *self-organization*.

Self-organization represents significant importance for complexity-based modeling and simulation. Per Bak notes that self-organized criticality is the basic engine for producing complexity in the real world. Self-organized criticality can occur when a complex system discovers an area within its environment that facilitates evolution [Bak, 1996]. Some complexity theorists call this area the *edge of chaos,* a site for innovation or adaptation. This is an area far enough removed from frozen order and not too close to the inscrutability of chaos, hence the notion of the edge of chaos. Perhaps we find this edge of chaos in the “sweet spot” of *emergence*, as shown in a notional discovery and decision-making environment in figure 1, below.

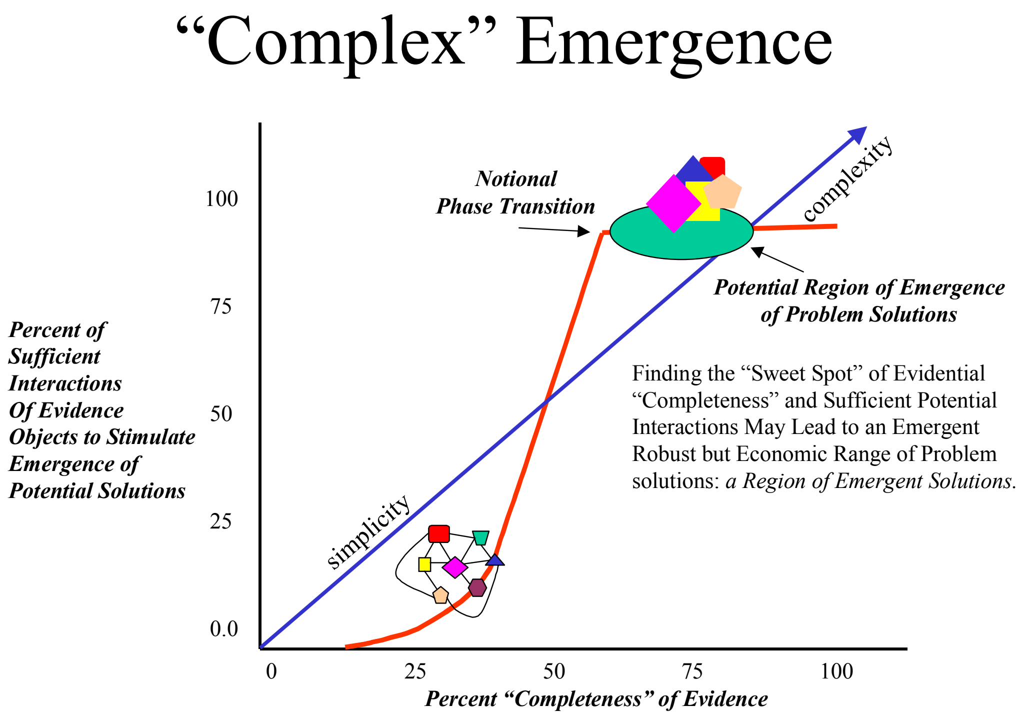

Figure 1: “Complex Emergence”.

This drawing depicts how a decision-maker may map a region of possible solutions that emerge through rich interactions of evidence, once a sufficient amount of evidence has been obtained. The thesis of this drawing is that once there exists a sufficiently “complete” set of evidence observations or data points, and these observations have been empowered to interact in an agent-based modeling environment for a “sufficient” amount of time, there will occur a phase transition that produces an environment for the emergence of a region of possible problem solutions. As occurrence of interactions of evidence proceed up the slope to this region (e.g., increasing), solutions progress from simple to complex, with the more complex solutions offering robustness in potential alternative solutions that encompass relevant critical items of evidence. An economy of solutions emerges that provides the decision-maker with new directions for query and understanding.

In the instance depicted above and indeed in general, “simple” solutions are preferred over “complex” solutions, but simplicity often obscures the power of interaction and interrelationship. Agent-based modeling such as the Agent Based Evidence Marshaling model discussed below is a candidate tool to parse complex interactions into simple visualizations where the detail is captured and available for study, if needed.

2.2 Evidence Organization: A Tool for Discovery in Complex Systems

This section begins with an examination of the work of David Schum and others as they have built upon many years of thinking about the organization of evidence and information to support better inquiry during fact investigation and more effective presentation of evidence before a court of law, a very high-level decision-making authority. At this point, it is important to consider evidence as a formalized description of information for decision-support in Command and Control as well as in criminal investigations and intelligence analysis. I briefly discuss an early prototype system called *MarshalPlan*, a computer-assisted but manual system for evidence marshaling that has received significant interest over the years of its development, including National Science Foundation support. Much of their writing on evidence marshaling and *MarshalPlan* points out the shortcomings of conventional methods of information organization, including Data Mining and Knowledge Discovery in Databases.

2.2.1 Evidence Marshaling and Discovery: The Inspiration and Backbone of Agent Based Evidence Marshaling

This paper posits one overriding theme: imaginative discovery of information in support of generating hypotheses and enhancing the process of inquiry in building and interacting with scenarios in Command and Control systems. David Schum and Peter Tiller's work on evidence marshaling provides a theoretical framework for expressing the most important observation and building block that permeates this theme. As Schum recently put it "how we marshal our thoughts and evidence has an important bearing on the discovery process itself as well as on the process of drawing conclusions from what we have generated or discovered" [Schum, 1999, 402]. Evidence marshaling is all about organizing masses of evidence to support imaginative discovery of "hypotheses, evidence and arguments" as Schum describes it, leading to more imaginative scenario building.

Evidence marshaling is an attempt to inscribe a bit of formality within the discovery process. In overview, it is quite simply a mechanism to support evidence organization and reasoning, but in concept it does so much more. Evidence marshaling places imaginative fact investigators "inside" their body of evidence, able to manipulate it in ways that allow the generation of new ideas, new evidence and new scenarios. Evidence marshaling allows the investigator to perceive more readily possible interactions among evidence items.

Schum points out that the generation of evidence is an important part of evidence marshaling, and that imaginative inquiry and scenario generation, as part of evidence marshaling, greatly facilitates this activity. I have yet to meet an investigator of any type who would reject assistance in generating evidence to support a claim or hypothesis. In fact, successful investigators will even welcome evidence to refute hypotheses, ala Francis Bacon. A major objective of Schum and Tillers, has been the following: to formalize the organization of evidence to aid the investigator in asking the "right questions" that could uncover critical links to evidence that either should exist or does exist behind the veil of complexity.

Even manual forms of evidence organization can be of assistance in this goal, as Schum and Kadane have shown in their analyses of complex criminal investigations and trial proceedings [Schum and Kadane, 1996]. My experience as a criminal investigator and my analysis of interviews with other investigators bears this out. Methods ranging from investigative notebooks (both manual and automated) to carrying around evidential observations on 3x5 cards exist throughout the legal, intelligence and scientific communities. These methods also reflect evidence marshaling techniques.

In 1987, Schum and Peter Tillers received support from the National Science Foundation to formalize discovery-related issues in fact investigation. They called the model formalized during this study

MarshalPlan. The mechanisms embodied in *MarshalPlan* can be integrated with graphing conventions first proposed in the 1930's by Henry Wigmore, arguably America's foremost scholar of evidence. Wigmore's Inference Networks are graph-based constructions of complex arguments based on evidence [Anderson and Twining, 1991]. He proposed that for an investigator or lawyer "to get the 'big picture,' we do need a picture showing how…statements or propositions fit together." In Schum's adaptation of Wigmore's work, the graph is composed of nodes and arcs. "Nodes consist of certain statements or propositions, and arcs specify their probabilistic linkages" [Schum, 1994, 162]. Schum's and Tiller's efforts have generated important discussions about several key points concerning evidential organization and reasoning.

As Schum notes, the way in which we organize our evidence greatly influences the questions we ask and the hypotheses we form about our evidence. "Thoughts and evidence organized or juxtaposed in one way can lead to significant insights that do not flash before us when these same thoughts and evidence are organized in other ways," notes Schum [1999, 402].[1] Schum and Tillers developed the idea of a metaphorical magnet to act as an attractor for organizing evidence in various ways. Within the *MarshalPlan* system a temporal magnet is one of the most commonly used and easy to visualize. As Schum indicates in his description of temporal magnets, "many of the trifles or details we gather, whether testimonial or tangible, are time-stamped [1999, 441]." The organization of evidence through event chronologies is an example of applying a temporal magnet. Temporal perspectives, particularly when combined within the space-time vectors that ABEM evidence object-agents employ, are of great important in the ABEM model.

Wigmore formalized the importance of using chronology in breaking out evidence in three ways within his network structure. Wigmore prescribed the use of prospectant, concomitant and retrospectant categories for organizing evidence. Prospectant evidence concerns events that may have occurred before the crime; concomitant evidence concerns events that may have occurred at or near the time of the crime; and retrospectant evidence concerns evidence about events that may have occurred after the crime [Wigmore, 1937]. Most importantly, however, is that the formation of "an event chronology is the first stage in generating stories or scenarios about what might have happened in the matter under investigation," writes Schum, in noting the importance of time as a magnet [Schum, 1999]. The telling of stories, or the generation of scenarios is a most powerful heuristic device in generating new hypotheses or possibilities.

Other marshaling magnets revolve around subjects such as case scenarios and possibilities, "eliminated" hypotheses, and evidential inquiry. There could obviously be many ways of categorizing matters under investigation, each of which could conceivably become a magnet. One can easily imagine the role relational database managers could have in organizing evidence around "key-field" magnets. Event scenarios and possibilities generally allow us to organize evidence around what we think may have happened in the course of the crime, or what conceivably could have happened.

2.2.2 Discovery and Inference: A Closer examination of Abduction and Semiotics

Are there ways to more effectively employ inference and discovery in building testable hypotheses for the scenario environment? Charles Peirce provides insight. He asserted that "this universe is perfused with signs…if it is not composed exclusively of signs" [Sebeok, 1983]. Peirce, and others even more recently, such as Gerald Schroeder, posit that the human mind is the natural interface to read these signs of nature [Schroeder, 2001]. Scenarios that we construct and explore within our minds help us to visualize these

[1] ABEM evidence object-agents graphically depict this observation, a central theme of this research. Also, note that the agents employed in the ABEM model are labeled object-agents in this paper to avoid confusion with the human investigators, such as Special Agents of the Federal Bureau of Investigation or US Army Criminal Investigation Command (CID).

complex relationships between man and nature – Einstein called these *gedanken* experiments. Peirce provided some formalization of the link between discovery and hypothesis in the following statement of reasoning he associated with the inference process he called abduction:

(Premise 1) The surprising fact, *P*, is observed.

(Premise 2) But if *H* were true, *P* would be a matter of course.

(Conclusion) There is reason to suspect that *H* is true. [Tursman, 1987, 13]

In this form, Tursman tells us that Peirce claims that the reason for thinking *H* might be true is that *H* would explain our observation of *P*. In Peirce's explanation, we assume that *H* had not occurred to us before as a hypothesis or explanation for *P* or any other evidence related to this line or reasoning. We only inferred *H* as a possible explanation because of the observance of *P*. In other words, because of the interaction of *P* with other evidence we have been observing, *H* emerges as a possible explanation for *P* and the other evidence we have observed. We likely did not consider *H* prior to the observance of *P*, and in fact discovered *H* as a result of observing *P*. Of course, we must now test *H* to ensure it also serves to explain the other evidence we may have observed prior to *P*. Scenarios are quite useful for this purpose. In addition, the investigator will be eager to see what new lines of evidence *H* allows us to generate. According to Tursman, Peirce notes "that an abduction concludes that such and such a hypothesis may be true and 'that the indications of its being so are sufficient to warrant further examination"[Tursman, 14]. Of course, such continued examination takes place through inquiry and inference, the lifeblood of the ABEM model, as shown below.

There are three basic types of inferential reasoning, each of which is conducive to machine-based support. The following table briefly describes these three types of reasoning methods that decision-makers must seek to master. This table does not, however, attempt to describe the various "shades" or mixtures of inference models that decision-makers might apply. Note that probability, as a means of assessing uncertainty, remains an important element of any study of inference.

Inference Model	Model Assertion	Description	Discovery Potential
Deduction	Normative	Reasoning from General to Specific; "shows what is necessarily so"	Structured, Ordered; Least Potential for Innovation
Induction	Descriptive	Reasoning from Specific to General; "shows what is probably so"; useful for patterns	Less Structured; Intuitive; More Potential for Discovery
Abduction	Heuristic	Inference to a Possible Conclusion; "shows what is possibly so"	Area for Maximum Innovation; A likely *Edge of Chaos*

Let us now assess this table and it's implications for decision-makers. The basic types of inferential reasoning described above rely only on their most basic meaning. *Deduction* is simply a process of reasoning from general knowledge to a specific conclusion. Webster's says "the conclusion follows necessarily from the premises"; if the premises are true, the conclusion must be true [Webster's, 1996, 520]. Deduction, notes Reisberg, is a process by which "we usually begin with a general statement and try to figure out what specific claims follow from it" [Reisberg, 1997, 442]. Deduction might be highly useful in cases where the information space supporting the investigator were "complete" in that it contained all the needed information to support proving a hypothesis, and the premises were consistent with the contents of the information space. This of course is very rarely the case at the onset of matters under investigation.

Induction, on the other hand, is more often applied as a model for probable inference to possible conclusions already generated or discovered [Schum, 1994, 47]. Turning to Webster's once again, we see that induction is a form of reasoning in which the conclusion is supported by, but not necessarily following from, the premises [Webster's, 975]. It is also known as reasoning from the specific to the general. In most cases, induction is the best a decision-maker can do in an imperfect world of missing or inaccurate information. However, induction, (especially when used in agent-based modeling) involves hypotheses that we already have at hand. Also, induction tends to support intuitive thinking, a tool upon which the vast majority of us rely on a daily basis. Reisberg notes, "in induction, we confront a sample of the evidence and seek to extrapolate from this sample" [483].

The final inference method depicted in the chart above is known as *abduction*. Webster's defines abduction as "a syllogism whose major premise is certain, but whose minor premise is probable" [Webster's, 3]. Peirce, the developer of the term abduction as it relates to inference, writes "The first starting of a hypothesis and the entertaining of it, whether as a simple interrogation or with any degree of confidence, is an inferential step which I propose to call *abduction*…" [Buchler, 151]. The importance behind Peirce's thinking is that abduction can simply be a question or hypothesis, in it's relative infancy, but it is more than a mere passing thought; it requires some notion of entertaining that thought in the form of hypothesis, question or idea. In "The Law of Mind", Peirce defines what he believes are the three components of an idea: "intrinsic quality as a feeling," "energy with which it affects other ideas," and "the tendency of an idea to bring along other ideas with it" [Buchler, 344]. Peirce further describes abduction as something that "comes to us like a flash" [304]. He continues, noting that abduction is:

> …an act of *insight*, although extremely fallible insight. It is true that the different elements of the hypothesis were in our minds before; but it is the idea of putting together what we never dreamed of putting together which flashes the new suggestion before our contemplation.

John Holland, et. al. write that abduction is a kind of inference that is routinely used in human thinking, particularly in solving crimes and diagnosing illness [Holland, et. al., 1986]. Abduction essentially involves justification, according to Holland. Josephson and Josephson [1994, 4] write that while deduction is "truth preserving," abduction is "truth producing," and that abduction involves "inference to the best explanation." The Josephsons claim that abductions may display "emergent certainty", a situation where the "conclusion of an abduction can have, and be deserving of, more certainty than any of its premises" [Josephson and Josephson, 15]. Compare this thinking to the accompanying discussions of emergence and it is not a difficult step to link abduction, discovery and emergence as powerful partners that can strongly influence the assessment of results found in agent-based scenarios. In any event, abduction is the process of generating what seems possible [Schum, 1994], and is clearly performed in an area of the investigator's imagination for maximum innovation, or perhaps even a sort of psychological *edge of chaos*. As we have noted, these ideas may also be visualized in the decision-maker's scenarios.

Finally, although not shown in the chart above, agent-based modeling is supportive of the reasoning methods described as a tool for discovery that allows us to *see what happens* or *what could happen*. We sometimes just don't know where to begin in developing our hypotheses or scenarios, or we want to discover patterns and relationships that only complex non-linear, mathematics might reveal. Or, perhaps we want to test our hypotheses in an environment that is less constrained than our pre-conceived notions and prejudices allow – such are the occasions on which agent-based modeling of evidence and interactions may show the greatest value. Compare this claim to Peirce's, Holland's and Schum's thoughts about abduction and ideas above. Interactions of ideas or evidence produce an environment for discovery, revealing what was really there all along but not visible until we could observe the results of the interactions. Holland and other complexity theorists call this *emergence*.

Discovery is important in this description of inference techniques. Discovery clearly involves seeing the world differently—perhaps even seeing things in a way that no one has seen them before. "When asked how he came to discover the theory of relativity, Einstein replied that he imagined how the world would look if he were riding on a beam of light" [Casti, 1997]. In a sense, Einstein not only saw the light, as it were, he became the light—he saw the world differently. If there is a way to introduce some formality into discovery-based thinking, it might be to provide a mechanism to think outside oneself – a scenario, perhaps? Arthur Koestler writes that discovery "often means simply the uncovering of something that has always been there but was hidden from the eye by the blinders of habit" [Koestler, 1964]. Koestler's definition is also supported by the definitions of discover and discovery in Black's Law Dictionary [1990]. Black's definitions discuss the process of learning what was always present but obscured. The machine-assisted process of discovery may be another area where agent-based modeling can aid the investigator in discovering what was always present, but hidden from sight by "the blinders of habit" or prejudice.

3.0 THE AGENT BASED EVIDENCE MARSHALING MODEL: A TOOL FOR DISCOVERY TO ENHANCE SCENARIOS

We now turn to a specific instance of a model that demonstrates the potential of enhancement of discovery in command and control systems through self-organization of data and information. This model, Agent Based Evidence Marshaling, was built on the thesis that self-organizing information systems enhance the process of discovery, and that the dynamic force behind this self-organization could be the simple process of inquiry. As the Schum *MarshalPlan* organized evidence around magnets such as time and location, so ABEM could marshal information, through self-organization, by empowering information to act as a local agent, curious to learn more about its place in the global construct of a scenario or event in question.

Agent-based modeling is a technique to model interactions between object-oriented representations of entities of interest. For example, to model behavior of amino acids involved in building a protein polymer chain in the process of protein replication, an agent-based approach might be to code the amino acids with characteristics that capture their chemical composition such as electrical charge and the ability to interact with ribosomal RNA. The RNA interaction ability would allow the amino acids to recognize a messenger RNA codon that sought a specific amino acid (and not another), in order to build an appropriate polymer chain. Agent-objects might be constructed to represent almost anything. ABEM agents were constructed to represent people as participants and witnesses to a crime, as well as inanimate objects that represented evidence in a crime. In agent-based modeling, emergent global behaviors emanate from the interactions of local agents, who may not even be aware of the global context in which they exist.

ABEM relies on the same process. The object-oriented capabilities of the Java programming language facilitated the development of ABEM, creating information objects, based on coded observations of an investigator into agent-objects capable of certain levels of autonomous interaction. When combined with the reasoning power and expertise of a human investigator, the interactions of the data objects of the ABEM model with the object-oriented autonomous nature of agent-based modeling did in fact produce enhanced potential for discovery. For the full detail on ABEM agent development and interaction, see [Hunt, 2001]. The principal point here is that potential for discovery through uses of agent-based scenarios for command and control also exists and can be inculcated into the NATO COBP.

3.1 Legos™, Technology Graphs and ABEM

In the initial development of efforts of ABEM it seemed straightforward to imagine fundamental observations of evidence as building blocks for hypotheses about an investigation. Chapter 8 of the COPB, Methods and

Tools, describes model federations in terms of Lego™ bricks. The ABEM Model Technology Graph shown below in Figure 2 reflects many of the building block components that Stuart Kauffman generally describes in technology graph ideas he presents in *Investigations* [Kauffman, 2000]. "A set of primitive parts and the transformation of those parts into other objects is a technology graph," notes Kauffman. "Technology graphs concern objects and actions, things and objectives, products and processes in a single framework," he continues [2000, 254]. Figure 2, depicting a precursor model to ABEM called by author James Herriot, "The Chair Model," suggests how objects and actions interact to produce products, such as a chair. This model is also described in *Investigations*.

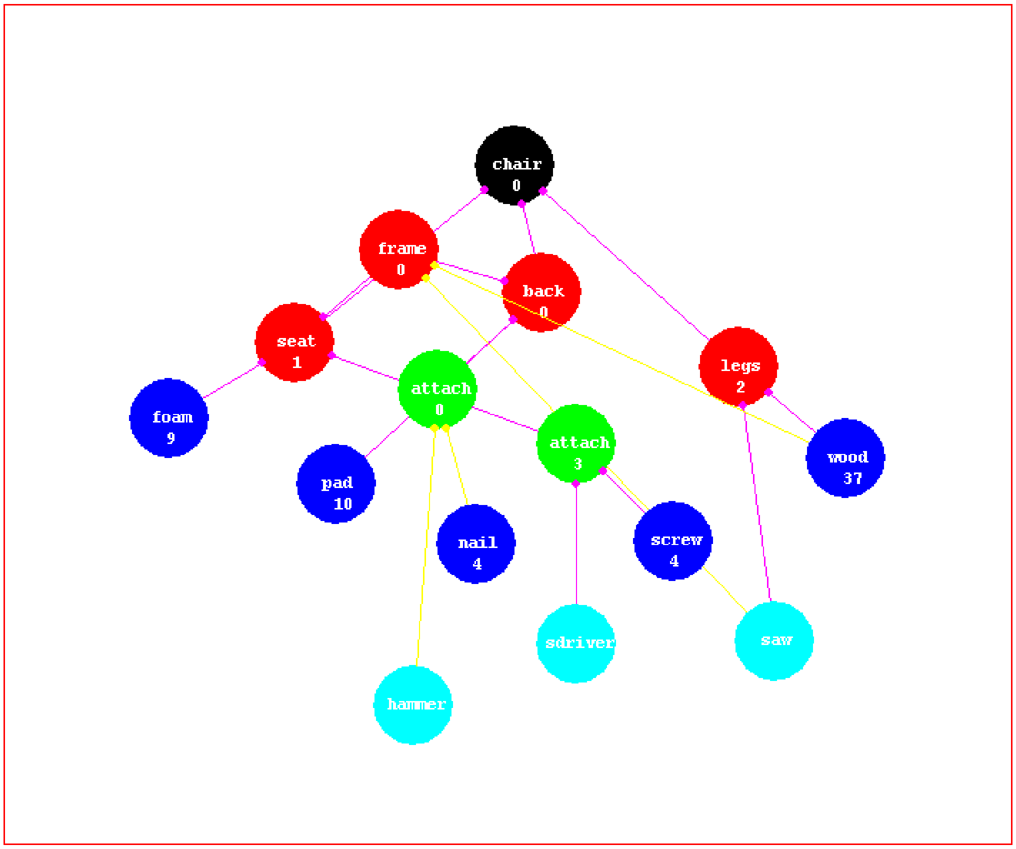

Figure 2.

A "self-organizing chair," depicts relative initial conditions before the construction of a "finished" chair. Like Legos, sub-components *seat*, *frame*, *back* and *legs*, leverage basic components *foam*, *pad*, *nail*, *screw* and *wood* to self-organize and build their sub-assemblies, which will eventually percolate into a final chair product. Note that there are already one *seat* and two *legs* sub-assemblies constructed At the bottom tier are tools *hammer*, *screwdriver (called "sdriver")* and *saw*, that are employed by the *attach* actions in the central part of the model to assemble the components and assemblies. Each of the object-agents has limited knowledge of only their most basic functions, knowing what they "need" (e.g., to be more complete) or what they "have" or "is" (e.g., what they can supply to those in need). *wood*, for example, does not "know" that it is a vital component to the finished *chair*. These agents do not gain experience or knowledge as a result of their interactions (as the agents in ABEM do). *The Chair Model was developed by Dr. James Herriot, Bios Goup, Inc., 2000.*

To express the ideas about technology graphs, Kauffman writes that he invented "Lego World", although my eleven-year-old son, Joshua, and many others like him would likely make similar claims. Regardless of its origins, Stuart Kauffman did demonstrate an extremely important idea with Legos and the environments one of any age can build with them: component objects, when allowed to interact, transform into typically more complex (and often) larger objects. The technology graph-based ABEM seeks to do precisely the same thing: transform evidence, via interaction, into complex scenarios, case theory and eventually testable hypotheses. In the ABEM framework, "objects and actions…" are simultaneously nurtured, and, through autonomous interaction, pointed towards the eventual goal of posing better questions by discovering what is already collected within the evidential database, and predicting what should be contained within it.

Kauffman remarks that the "first thing to notice about the Lego World technology graph is that it might extend off into infinity, given an infinite number of primitive Lego parts" [2000, 224]. This would clearly not be a feature that a criminal investigator or C2 decision-maker would seek to leverage, supposing that she heard this first feature out of context of the remaining thoughts on technology graphs. The key is obviously to keep a check on what can become a primitive part without inhibiting discovery. To constrain this possibility, Kauffman proposes the use of a technology graph grammar such as the *is a*, *needs a*, *has a* grammar construct discussed in Kauffman's *Investigations*. "In Lego World, the grammar is specified by the ways primitive blocks can be attached or unattached, and by any designation of which Lego objects can carry out which primitive construction operations" [*ibid*.] So, grammar constrains combinatorial explosiveness, a significant concern in any model in which many objects are allowed to interoperate in relatively unconstrained fashion.

3.2 A Closer Look at ABEM

Figure 3, below, depicts the basic architecture of the ABEM model, extending beyond the simple grammar-based constraints of the chair model. Reading from bottom to top, the Data Source and DBMS layers describe the traditional methods of organizing data, specifying how ABEM might integrate with existing database systems. The Evidence Marshaling layer defines interfaces to an information organizing strategy such as the Schum-Tillers *MarshalPlan* model. The ABEM Agent Interaction layer describes how agents are constructed and interact through grammar and query, as discussed above. The Scenario Generation layer, perhaps the most interesting aspect of the model for scenario generation and assessment as discussed in Chapter 7 of the COBP, defines how agents interact with each other, the decision-maker and the environment to produce self-organizing scenarios and hypotheses. The final two layers, Hypothesis Formulation and Argument Construction and Testing, describe processes for how decision-makers might interact with the results of the scenarios generated and how these results might be articulated into testable hypotheses and arguments.

The ABEM layers depict relevant sub-component processes that influence the transmittal of information in ABEM from one layer to another and between processes. Thanks to Schum and Tillers, more research of the Evidence Marshaling Layer exists and has been documented as noted. The Agent Interaction and Scenario Generation layers are the primary focus in this paper. The higher layers, Hypothesis Formation and the Argument Construction and Testing are only now being developed by Stuart Kauffman, Bruce Sawhill and Jim Herriot, as part of their work in understanding Boolean expressions as means of expressing complex information relationships [Kauffman, 2000]. All layers, however, are important to an eventual end-to-end ABEM architecture. [See Hunt, 2001 for detailed information about each layer.]

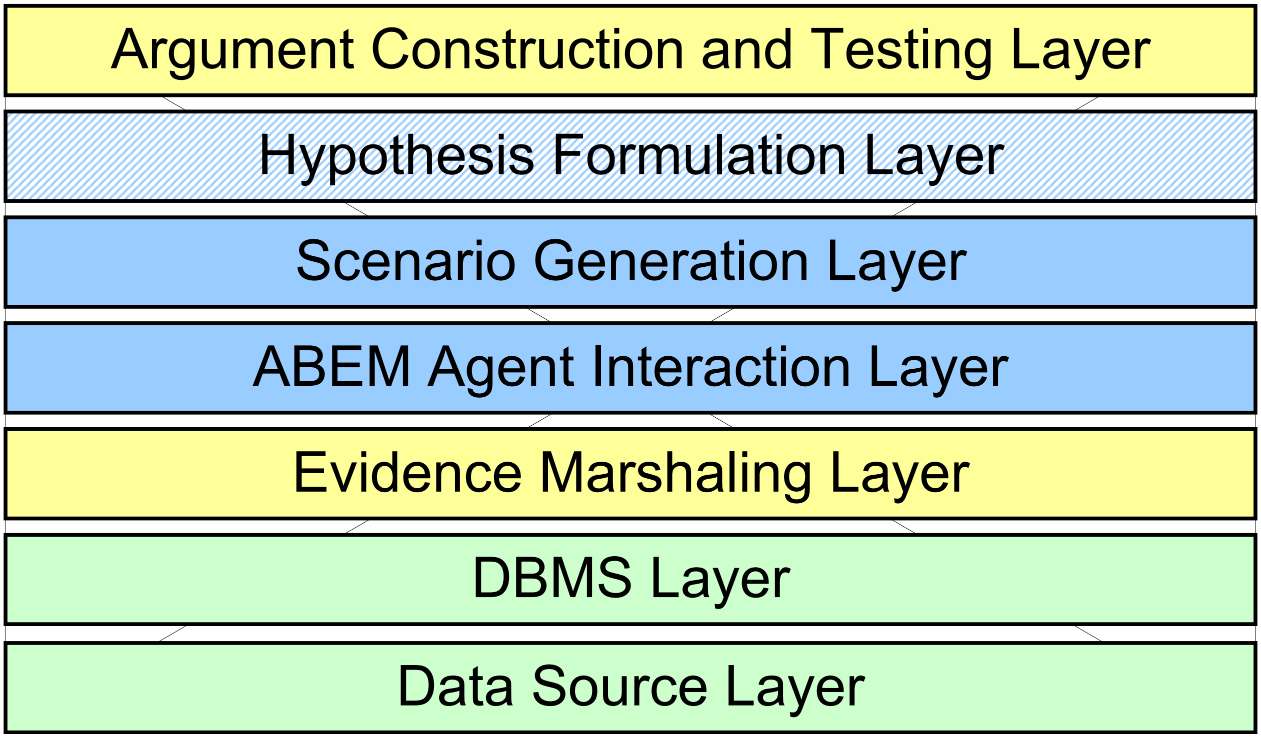

Figure 3: ABEM Architecture.

Before describing the Scenario generation components of ABEM, a brief note about ABEM agents is in order. ABEM evidence object-agents are built upon the tuple construct, a message-passing device. Tuples are also known as tags. Tuples originated with Yale computer scientist David Gelertner and were significantly documented in works produced by Gelertner, Nicholas Carriero and others through the mid-1980s and 1990s. The programming language in which Gelertner specified tuples is called *Linda*. The *Linda* programming language, developed at Yale University by Gelertner, Carriero and others, was introduced as a control and coordination language for parallel and distributed processing. Linda focuses on the creation of activities, the synchronization of these activities and communication among the objects of these activities. It was optimized for parallel processing of single programs [Ciancarini, 1996].

Tuples were originally applied as constructs for improving parallel processing performance in relational database management systems and have had a strong influence in the development of several contemporary proposals for control and accessibility to network appliances and data sources. In the latest applications of distributed networks, such devices pass tuples between each other in their search for information about previously unknown resources on the network. Both Sun Microsystems and IBM have applied tuples as message-passing devices in their *JiniSpaces* and *T-Spaces* research, respectively.[2]

[2] See generally the following papers for more detail on various implementations of tuples and the *Linda* programming language: "JavaSpaces Specifications", Sun Microsystems, Palo Alto, CA, report dated 7/17/98, accessed at: http://chatsubo.javasoft.com/products/javaspaces/specs/js.pdf, accessed on 11/14/2000; and Wykcoff, P., et. al., "T-Spaces", IBM Systems Journal, Volume 37, No. 3, 1998, accessed at: http://www.research.ibm.com/journal/sj/373/wyckoff.html, accessed on 11/14/2000.

ABEM also makes use of similar types of tuples, although in a slightly less structured format to ensure that an environment of maximum flexibility exists. The designer of the ABEM tuple construct, Jim Herriot, removed some of the constraints from Gelertner's original design in order to ensure discovery and inference can take place. Bear in mind that Gelertner and others who have extended his work did not necessarily seek these properties. In the original ABEM work, tuples are utilized to pass information about time and space in order to build vectors for decision-makers to follow more easily.

The Scenario Generation Layer of the ABEM architecture reflects an area of interest for the COBP. Contained within this layer are the components of *substitution*, as well as other grammatical constraints beyond the scope of the current discussion. The concept of *substitution* is of course related closely to Kauffman's description of substitutes (and complements), as presented in *Investigations* [Kauffman, 2000]. While the example below serves to define substitution in the ABEM context, substitutes allow one object to be referred to by another very similar object, following the ideas of semiotics. In the Chair Model case above, a nail might be substituted for a screw when applying the process of fastening two object agents together as a sub-assembly. Substitution is also related to what Marvin Minsky calls "multiple representations," when he expresses what he calls "commonsense thinking" [Minsky, 2000, 71]. As Minsky writes:

> If you understand something in only one way, then you scarcely understand it at all because when something goes wrong, you'll have nowhere to go. But if you use several representations, each integrated with its set of related pieces of knowledge, then when one of them fails you can switch to another. You can turn ideas around in your mind to examine them from different perspectives until you find one that works for you. And that's what we mean by thinking! [Minsky, 67].

ABEM *substitution* does not pretend to empower machine thinking, but it does allow the decision-maker to observe data representation from different perspectives as the object-agents seek substitutes for themselves during the query process. In figure 4, below, an actual ABEM model screenshot, note the interaction between the *truck* object-agent and the *box* object-agent. The initial ABEM model represented in this research attempts to help an Army criminal investigator notionally locate a stolen computer and learn about the identity of the thief. This scenario is documented in detail in [Hunt, 2001].

In the example shown below, object-agent *box* is asking object-agent *truck* if it knows of a substitute, or *multiple representations* in Minskey's terms, for itself. Truck responds affirmatively that it knows about the possibility of a substitutionary relationship of *box* for *truck*. Such a representation is possible for several reasons. The first reason is that the investigator, as he engaged in the early phases of initializing and embedding marshaled evidence, explicitly listed this substitution as possible based on prior knowledge or access to previously collected information in related databases. It is also possible that the object-agent queried the investigator interactively for guidance. The third reason this substitution is possible is based on the notion of *affordance*, the capacity for bearing the "cost" of the relationship.[3] In this example, a truck can "afford" to carry the box, but it is not possible for this box to carry the truck. Such affordance relationships are often useful in avoiding circular relationships that increase the computational burden of search.

[3] This preliminary definition of affordance is based on personal conversations with Stuart Kauffman about constraining the potentially out-of-control activities of object-agents when relying on substitutions to expand the "vision" of these agents engaged in identifying themselves or building relationships with other agents or their environment. See also Axelrod and Cohen [1999, 6], where they define affordance as the feature of non-agent based artifacts that are capable of evoking certain behaviors of agents. According to Axelrod and Cohen, these artifacts are basically objects capable of being used by agents, or objects that can support agent function.

Figure 4 is an actual ABEM screenshot depicting the interactions of two object-agents, *box* and *truck*, as *box* seeks to further identify itself. As shown by the lighter colored arc between the two (with a dotted termination point at *box's location*) *box* queries *truck*, in a random manner, to determine if *truck* knows of any substitutions for itself (shown as "needsa sub box"). *Truck* replies that it knows of a substitutionary relationship, namely that it can be substituted for *box* (shown as "knowsa sub box truck"). *Box* incorporates this information into its knowledge table (as discussed in Figure 5). Box then subsequently begins to build a space-time vector for *truck* since it now "assesses" truck's location to be important. Also in view at the top right corner of the figure is a tuple query from object-agent *Liles*, an agent representation for one of the human witnesses in this case. *Liles* is asking one of the other object-agents for information about his own location at a certain point in time. This question may seem less sensible for "human" agents, but is valuable for inanimate objects such as *box*. *The ABEM Model code was written by Dr. James Herriot, Bios Goup, Inc., 2000.*

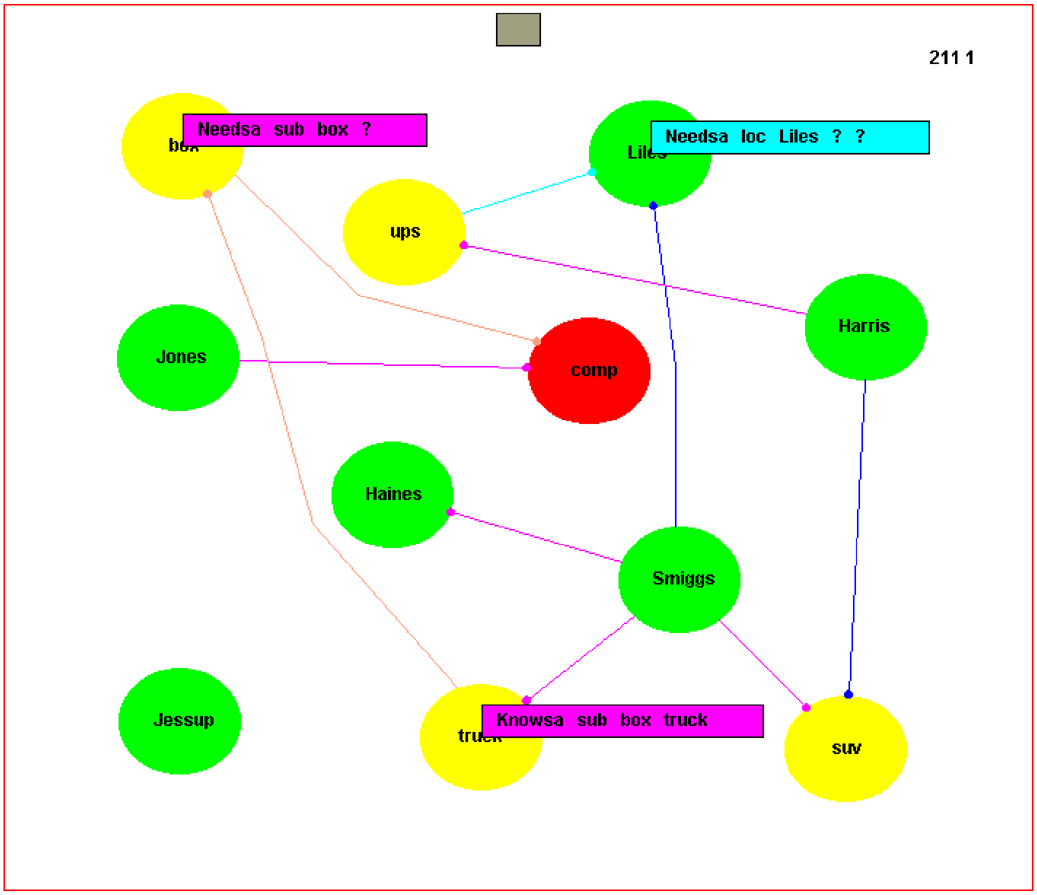

Figure 4.

The substitutionary component of the ABEM Scenario Generation layer empowers what very much appears to be similar to human inference. Noting again the screenshot and description contained in figure 4, it is apparent that the computer object-agent, *comp*, has learned an appropriate substitutionary relationship between itself and *box*. This means that *box* can afford to carry *computer*, as earlier defined by the investigator. Once *computer* has inculcated that information into its knowledge table, as shown above, it begins to fashion queries about the space-time vector and other substitutionary relationships for *box*. In other words, it begins to track *box* because it is now interesting to do so – where *box* is located, *computer* may also be located. Also note that it is desirable for an object-agent to interact with the investigator to ask the investigator if certain substitutionary relationships can exist. The particular example of *box* asking the investigator if it can be a substitute for *computer* is in fact modeled in ABEM. Other grammatical constructs are described in [Hunt, 2001].

Although not shown in the ABEM model run in Figure 4, an object-agent knowledge table captures the tuple-based information with which an object-agent is instantiated as well as new information derived through interaction with other agents. This table captures the results of ABEM object-agents' learning through interaction. Figure 5, below, depicts the likely use of an ABEM knowledge table to build scenarios and hypotheses. The table shown is a reconstruction of the object-agent *computer's* table taken from an ABEM model run. The scenario-generation feature described below, while not currently implemented, suggests how the tuple entries from the knowledge table could be "reverse-parsed", through natural language processing techniques to produce the accompanying scenario. Each of the sentences and phrases to the right of the box are backed up by one or more tuples. The final statement, at the bottom of the scenario, represents a candidate hypothesis that could be extracted from the scenario statement for encoding and testing.

ABEM "Knowledge" Table

comp
loc comp b0830 trailer
sub comp box
sub box truck
sub box suv
loc suv 1115 river
sub truck ups
sub ups truck
loc truck a0950 parking
loc truck a0950 road
loc ups 0950 river
loc box a0950 walkway

comp

Computer "reasons": I was last seen in the trailer before 0830 – anything that happened to me in this investigation before that time is not important to me. I discovered through query with other agents that the box could be a substitute for me, meaning the box can afford to contain me (principle of *affordance*). I then discovered that the truck can substitute for the box, which again means that if could be contained by the box, I could be contained by the truck. Based on my discovery of the substitutionary relationship between the SUV (suv) and box, I know that I could also be carried by the SUV, because both the truck and the SUV can carry the box. Therefore, I better track time-space (location) vectors of the box, truck and SUV, and perhaps I'll learn where I could be at those points in time. I see by the responses that I've received to this point in the current model that my time-space vector could be: 08:30-trailer; 09:50 walkway (box); and then parking lot (truck) and then road (truck); and finally 11:15, river (SUV). I could therefore hypothesize the following: ***Sometime after 08:30, I was stolen from the trailer, placed into the box about 09:50, carried along the walkway to the truck, and then transported via the truck from the parking lot on to the road, and ended up by the river, in the SUV at 11:15.***

Figure 5: ABEM Knowledge Table Parsing.

The box on the left side depicts an actual emergent ABEM knowledge table constructed from object-agent interactions. The text on the right suggests how the tuples in the knowledge table could be interpreted through natural language processing (a "reverse parsing," perhaps) to build a scenario derived only from agent interactions. The phrase at the bottom of the scenario suggests a more concise hypothesis that could then be coded for testing, as briefly discussed in the ABEM architecture above. For more detail, see [Hunt, 2001].

The principle objective for the original ABEM model was manifested in the development of self-organized scenarios that could suggest tip-offs to what the *unknown unknowns* might be. When examining the agent-assisted scenario at the right of Figure 5, above, for example, a decision-maker might note holes in the chronology or physical space parameters and generate new lines of inquiry based on what she determined to be missing, or unknown. Following the inspiration of the Schum-Tillers *MarshalPlan*, it was of paramount importance to increase the decision-maker's visibility of what was missing that should be part of the puzzle – to instruct on what was not known, but should be known in order to solve the mystery. With the publication of the recent NATO Code of Best Practices, this objective dovetails well with how decision-makers can better interact with scenarios. I now conclude with how ABEM and semiotics might improve this critical process for enhancing C2 best practices.

4.0 ENHANCING C2 BEST PRACTICES WITH ABEM AND SEMIOTICS

Chapter 7 of the NATO Code of Best Practices provides some essential elements of definitions for scenarios within the context of Command and Control. The COBP notes that the composition of a scenario includes a geopolitical context, the various participants involved in a given situation, the overall environment, and the evolution of the events in time. "In C2 assessments, the purpose of scenarios is to ensure that the analysis is informed by the appropriate range of opportunities to observe the relevant variables and their interrelationships," [COBP, Chapter 7, 2001]. As Command and Control assessments involve many non-linear phenomena such as human and organizational behaviours, as well as environmental conditions that transcend human control, linear modeling techniques provide limited insights into the complex relationships that exist between the elements typically modeled in scenarios.

"In essence, the role of a scenario is to define a set of conditions and restrictions to enable 'good' analysis as well as to create a structure within which the results of the analysis can be understood and interpreted," adds the COBP. It is worth noting that the scenario should provide for "good" analysis rather than the "best" analysis. The authors of Chapter 7 of the COBP appear to intuitively understand the parallels of emergent scenarios and evolution. Evolution does not seek the "best" solutions, and neither should scenarios. The purpose of scenarios whether in the context of command and control planning, intelligence or legal analysis or even scientific research, should be to reveal insights about the interactions of objects of interest within a given environment – to facilitate discovery, in other words. The component objects of scenarios, as defined by Chapter 7 of the COBP are good candidates for object-agents in the agent-based modeling world suggested by ABEM.

4.1 Command and Control Best Practices and ABEM

In section 3, I described some basic characteristics of object-agents in general and how these characteristics were manifested in ABEM agents. ABEM agents are software representations of both animate and inanimate objects: participants and witnesses to a crime, as well as vehicles, the stolen computer and various items of testimonial evidence that were a blend of both living and non-living representations. The development of these agents is as much art as science. If a decision-maker is seeking true emergence, she would ensure that the agents were instantiated with enough (but not too much) information in order to interact with other agents and learn. The power of emergent discovery comes from interaction, and the temptation to capture every detail in code for every object-agent must be avoided. Object-agents need just enough information to make them suitable as donors and learners.

The same point applies to Command and Control agent-based modeling. Many of the procedures and bits of intelligence that a planner uses in his efforts are suitable for object-agent encoding. ABEM objects demonstrate how one might encode testimonial evidence and provide for observations of inanimate objects. Might a C2 planner also be able to encode relevant aspects of "best practices" and allow them to interact with fresh intelligence information obtained dynamically from sensors to produce new scenario-based decision-making aids? Apparently, from a reading of the 2001 Code for Best Practices, these new modeling technologies are already under review.

The ABEM model represents a methodology for producing evolutionary, emergent scenarios that can aid in the C2 decision-making process. Evolution is the key word. Life has been successful in the last few billion years because it has found a way to do good things, not necessarily the best things. Seeking the best is expensive and often results in marginal increases in return on investment. This statement does not imply that seeking and sharing "Best Practices" are ill-advised. This is a case of where the journey is more important than the destination. We must seek better ways to defend our national entities and stop aggression before it actually strikes – this is particularly true of terrorism. Given fewer resources than most NATO countries possess, it is highly likely that terrorist forces seek solutions that are good enough to accomplish their mission rather than the "best way." Life works exactly the same way.

Enhancing the process of discovery in planning will result in a certain improvement to C2 best practices. Agent-based modeling, applied in novel ways that produce emergent discovery will augment any planning effort. Understanding the way life and nature work and finding ways to emulate their successes will also improve Command and Control best practices. Mechanistic approaches reflect what's "best" about the way man has typically modeled nature. There's much more to it than that.

4.2 Infusing Command and Control Best Practices with Semiotics

If semiotics is the study of signs and systems that produce and use signs, there are also other ways that nature and the systems that emerge from nature communicate with us. Semiotics scholar Umberto Eco adds two other communications capabilities that nature (including mankind) uses to provide insightful information to us: symptoms and clues. Symptoms, according to Eco, represent deductive methods of communications. "In symptoms the type-expression is a class of ready-made physical events that refer back to the class of their possible causes," [Eco, 1983, 211]. He explains that the pattern of dust on a table, for example, is the symptom that brought about its dispersion or template. A decision-maker can deduce, with confidence, from a symptom to a cause – the presence of the effect or sign the symptom leaves behind is directly tied to the cause.

Clues, on the other hand, notes Eco, are more inductive in nature. "Clues…are objects left by an external agent in the spot where it did something…so that from their actual or possible presence the actual or possible past presence of the agent can be detected." The difference, Eco tells us, is in actual presence versus possible presence:

> In a way clues are complex symptoms, since one must first detect the necessary presence of an indeterminate causing agent and then take this symptom as the clue referring back to a possibly more determined agent—conventionally recognized as the most probable owner of the object left on the spot. That is why a criminal novel is usually more intriguing than the detection of pneumonia. [ibid, 211-212]

Signs, symptoms and clues all feed the process of abduction. The function of probability comes most into play in considering just how much reliance a decision-maker can have in semiotic-based reasoning and discovery.

Eco speculates that in "real" life detectives make more frequent mistakes than scientists because they are "rewarded by society for their impudence in betting on meta-abduction." Peirce defined meta-abduction as wagering on the likely end results without waiting for the results of intermediate observations. Scientists can usually afford to be more patient and test from one intermediate result to the next – their abductions methodically becoming true deductions, where results necessarily follow from observation. C2 planners probably fall somewhere in between, but may lean more toward detectives.

Abductions, in a form Eco calls "undercoded", are "world-creating devices" [ibid, 214]. Such a description sounds a great deal like agent-based modeling. If decision-makers build their models in ways that better harness signs, symptoms and clues (the essentials of semiotics), allowing for interaction and emergence, their models are likely to better represent the nature of the real world and its primary force for change and growth, evolution. If models are appropriate to capture this real-world nature, then agent-based models are likely to be the technique of choice to capture emergence.

Physicist Gerald Schroeder recently wrote that "It is because we are a part of the universe that has become aware," that we have recently been successful at beginning to understand the wisdom contained within even the smallest of the particles that compose nature. "…at every level of complexity, the information that emerges from a structure exceeds the information inherent in the components of that structure" [Schroeder, 2001, 178]. In other words, the ancient maxim "the whole is greater than the sum of its parts" continues to be validated time and again.

Schroeder implies that it is our human mind that uniquely interfaces with nature to produce the understandings that we have of the universe, "a world unrealized at the unconscious level, but still very real in its impact upon the world our conscious physical senses can access" [ibid, 127]. I believe that most semioticians would agree and hasten to point out that it has been the thrust of semiotics to exploit those connections between the mind and nature. For the time being, agent-based modeling, infused with an effective dose of semiotic thinking may be one of the best ways to model those interfaces into nature.

4.3 Conclusions

This paper has examined ways to blend into Command and Control Best Practices more effective use of semiotics, modeling and scenarios. I have shown the agent-based model as a type of novel modeling technique for scenario generation and interaction, as well as infusing into this study some philosophical consideration of semiotics and discovery. I have demonstrated that natural, evolution-mimicking techniques stand ready to enhance the process of discovery and modeling, particularly as it applies to NATO's consideration of best practices in Command and Control planning and execution.

As members of the political and military planning community, we must exercise caution in thinking about our efforts as "revolutionary." Life, as we might observe in agent-based modeling, teaches us the more subtle insights about our role on this earth in terms of evolution. We must adopt the long view, however, in order to see where we actually fit in. The closer we can emulate real life, including how we model it and interact with it, the more likely our successes in complex planning endeavors. The application of agent-based modeling to enhance the process of discovery within our information space will clearly accompany best practices of command and control for the future. Time is short; we should include these practices now.

5.0 REFERENCES

Anderson, T., and Twining, W., "The Trial Lawyer's Standpoint", in *Analysis of Evidence*, Northwestern Press, Chicago, 1991.

Axlerod, R., *The Complexity of Cooperation*, Princeton University Press, Princeton, NJ, 1997.

Bacon, F., *Novum Organum*, "Book II, Aphorisms 2 and 40", Open Court Publishing, Chicago, 1994.

Bak, P., *How Nature Works*, Copernicus, Springer-Verlag, NY, 1996.

Black, C., et. al., *Black's Law Dictionary, Sixth Edition*, West Publishing Co., St. Paul, MN, 1990.

Blackmore, S., *The Meme Machine*, Oxford University Press, Oxford, UK, 1999.

Buchler, J., *Philosophical Writings of Peirce*, Dover Press, NY, 1955.

Carriero, N., and Gelertner, D., *How to Write Parallel Programs: A First Course,* MIT Press, Cambridge, MA, 1990.

Casti, J., *Would-Be Worlds*, John Wiley & Sons, NY, 1997.

Ciancarini, P., et. al., "PageSpace: An Architecture to Coordinate Distributed Applications on the Web", presented at: Fifth International World Wide Web Conference, May 6-10, 1996, Paris, France, accessed at: http://www5conf.inria.fr/fich_html/papers/P5/Overview.html, accessed on 1/15/2001.

Dawkins, R., *The Selfish Gene*, Oxford University Press, Oxford, UK, 1989.

Eco, U, "Horns, Hooves, Insteps: Some Hypotheses on Three Types of Abduction", *The Sign of Three*, Indiana University Press, Bloomington, IN, 1983.

Holland, J., et. al., *Induction*, MIT Press, Cambridge, 1986.

Hunt, C., *Agent Based Evidence Marshaling*, Doctoral Thesis published at George Mason University, Fairfax, VA, 2001.

Josephson, J., and Josephson, S., *Abductive Inference*, Cambridge University Press, Cambridge, 1994.

Kadane, J. and Schum, D., *A Probabilistic Analysis of the Sacco and Vanzetti Evidence*, John Wiley and Sons, NY, 1996.

Kauffman, S., *Investigations*, Oxford University Press, Oxford, UK, 2000.

Koestler, A., *The Act of Creation*, Arkana-Penquin Books, London, 1964.

Minsky, M., "Commonsense-Based Interfaces", Communications of the ACM, Vol. 43, No. 8, August, 2000.

NATO Code of Best Practice for Command and Control Assessment, Revised Edition 2002.

Reisberg, D., *Cognition: Exploring the Science of the Mind*, Norton & Company, NY, 1997.

Sebeok, T., "One, Two, Three Spells UBERTY", *The Sign of Three*, Indiana University Press, Bloomington, IN, 1983.

Schroeder, G., *The Hidden Face of God*, Free Press, NY, 2001.

Schum, D., *Evidential Foundations of Probabilistic Evidence*, John Wiley & Sons, NY, 1994.

Schum, D., "Marshaling Thoughts and Evidence During Fact Investigation", *South Texas Law Review*, Vol. 40, No. 2, Summer, 1999.

Tursman, R., *Peirce's Theory of Scientific Discovery*, Indiana University Press, Bloomington, IN, 1987.

Waldrop, M., *Complexity*, Touchstone Press, NY, 1992.

Webster's New Universal Unabridged Dictionary, Barnes and Noble Books, NY, 1996.

Wigmore, J., *The Science of Judicial Proof as Given by Logic, Psychology, and General Experience, and Illustrated in Judicial Trials*, Little, Brown & Company, Boston, 1937.

Wilson, E., *Consilience: The Unity of Knowledge*, Alfred A. Knopf, NY, 1998.

6.0 LIST OF ACRONYMS

ABEM	Agent Based Evidence Marshaling
ABM	Agent-based modeling
C2	Command and Control
COBP	Code of Best Practices

AUTHOR BIOGRAPHY

Lieutenant Colonel Carl W. Hunt, Ph.D., is the commander of the US Army Criminal Investigation Command's Computer Crime Investigative Unit, and is the organizer and moderator of an annual Smithsonian Institution lecture series on the applications of Complexity Theory in day-to-day life. He has published several papers about the application of agent-based modeling and semiotics to the complex problems associated with making sense of masses of information.

This page has been deliberately left blank

Page intentionnellement blanche